EVALUATION OF

ELECTROFISHING-INDUCED SPINAL INJURIES

RESULTING FROM FIELD ELECTROFISHING

SURVEYS IN MONTANA

by

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MARCH 1, 1992

ACKNOWLEDGEMENT

The author wishes to thank Jeff Bagdanov who was a wizard with the fillet knife and also absorbed a lot of errant rads at the x-ray table to produce these results. Special thanks to the staff and Drs. Ron Stafford and Greg Lovgren at Gallatin Veterinary Hospital who put up with a lot of fishy odors which drove their feline patients crazy. They generously provided access to their x-ray machine and interpretive support. Keith Aune and his crew in the Wildlife Research Lab at MDFWP were similarly tolerant even though their odors outranked ours. George Liknes, Paul Hamlin, Steve Leathe, Scott Rumsey, and Gary Anderson conducted the preliminary testing which led up to this research. Biologists from all over the state generously contributed time and effort to collecting these samples, including Scott Rumsey, Don Peters, Chris Clancy, Ken Frazier, Mike Vaughn, Phil Stewart, and Vic Riggs. The Department Electrofishing Committee comprised of Howard Johnson, Don Peters, George Liknes and Wayne Hadley planned and guided the study and reviewed the manuscript. In return for all their help I wish each and every one a lifetime free of spinal injuries!

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ABSTRACT

Examination of 693 trout sampled from Montana rivers by electrofishing was conducted to document the incidence and severity of electrofishing-induced spinal injury. A total of 769 hemorrhages and 2,647 injured vertebrae were documented, categorized, and described. Substantial evidence demonstrated that 60Hz pulsed DC current results in excessive injury rates to both rainbow (60-98% injury) and brown trout (44-62% injury) regardless of waveform (rectified sine-wave or square-wave), water conductivity (33-900 umhos/cm), or equipment design variables. Longer trout did not show a noticeable trend toward higher injury rates, but fish with "brand" marks did exhibit higher spinal injury rates. Limited sampling of arctic grayling, sauger, and shovelnose sturgeon did not reveal spinal injury problems with these species. A discussion of electrofishing efficiency and proposed guidelines to minimize spinal injury are included.

INTRODUCTION

A paper published in the Winter 1988, North American Journal of Fisheries Management, alerted biologists in Montana that significant spinal injury to fish might be occurring due to electrofishing (Sharber and Carothers, 1988). That study found that nearly half of the large rainbow trout electrofished on the Colorado River were injured despite attempts to minimize injury rates.

Followup tests conducted in Alaska (Holmes et al. 1990) and in Montana on the Missouri River in late 1988 by the Montana Department of Fish, Wildlife and Parks (MDFWP) confirmed 50-70% of the rainbow trout were incurring spinal injuries. Very few of these injuries were externally visible. Based on these data, the MDFWP issued interim electrofishing guidelines which emphasized the importance of using pulse frequencies of 20 pulses per second or less, short pulse duration (5 msec.), and lowest possible voltages to minimize injury.

Unfortunately, continued testing found that while the guidelines were successful in reducing injury, the low pulse frequencies made capture efficiency very poor. Additional sampling in 1989 and 1990 on the Missouri, Flathead and Kootenai rivers as well as other waters continued to document the scope and nature of the spinal injury problem but provided no solutions.

The preliminary evaluations led to the development of a study plan and subsequent research presented in this report. The objectives of this study were to systematically evaluate the factors related to electrofishing which play a role in spinal injury and to provide recommendations for solving the problem.

METHODS

A study plan was developed to collect specimens from wild populations in a consistent and reproducible manner. The sampling protocol and analysis procedures were standardized (Appendix A). Water temperature and conductivity were recorded before and after each sample collection. The type of equipment, electrode array design, and electrofishing settings were documented and summarized (Appendix B). The average power gradient (v/cm) was recorded at measured intervals from the electrode. Measurements were made using a set of metal contacts 1 cm apart mounted on a probe and connected to a digital voltmeter. Subsequent analysis of waveforms with an oscilloscope showed that these voltage gradient readings varied depending on the type of waveform in use and did not truly characterize the intensity of the field. They were of limited value and are not reported.

Samples were brought into the lab and individual fish were marked and frozen within 24 hours of capture. Within three months,

samples were x-rayed and autopsied. Fish were partially thawed and X-rays were taken at a local veterinary hospital. Duration of exposure to x-ray varied from 0.4-1.0 seconds at 40 kilovolts; larger fish were exposed for longer periods. Standard veterinary x-ray film was used (3M Brand, No. 1414).

After the fish were x-rayed they were autopsied. Autopsy was most effective on specimens that were 3/4 thawed but still firm and slightly crystallized along the spinal column. Fish were autopsied using an electric fillet knife to remove the fillet on the left side of the fish. One technician conducted the autopsy while another studied the x-ray for abnormalities and recorded observations. Consensus was achieved on questionable injury ratings. Each hemorrhage was rated according to preset criteria (Table 1), and its location designated by measuring from the tip of the snout to the center of the hemorrhage. The left side of the fish, with fillet exposed, was photographed for later reference. The autopsy process was repeated for the right side. The overall hemorrhage rating designated for each fish was the highest rating for any individual hemorrhage. X-rays were not permanently marked during the autopsy.

Following completion of all autopsy work x-rays were examined and rated. X-rays were grouped into test groups (e.g. all x-rays from brown trout on the Madison River using three different waveforms) and then randomly shuffled to eliminate bias. X-rays were examined, marked, and recorded according to pre-established injury criteria (Table 1). Vertebrae were numbered beginning at the head. The first well-defined vertebra behind the skull was typically the first vertebra with a dorsal process. Each injured vertebra was rated. In some cases, the outer limits to minor compression injuries were difficult to determine.

Autopsy and x-ray results were compared for each individual fish to determine consistency between methods and to identify obvious errors. This is discussed in detail in the results.

Injury classifications presented are combined ratings from autopsy and x-ray. Whichever rating was higher, autopsy or x-ray, became the rating for that fish. The "average severity rating" or ASR for a sample group was the arithmetic mean of the combined individual ratings.

An effort was made during the collection process to achieve sample sizes of 50 fish for each group. A sample of 50 fish allowed us to detect a 20% difference in injury rate at about an 80% confidence level (Snedecor & Cochran 1967). Several hundred fish in each group would be necessary to provide statistically valid results. Such large sample sizes were impractical given the limitations of this study. Thus, most conclusions presented are not accompanied with statistical analysis.

Evaluation of electrofishing waveforms is a complex area of concern. Electrical waves can be varied and altered in numerous

Table 1. Spinal injury evaluation ranking criteria (Reynolds 1992).

X-Ray --- Used to evaluate spinal damage.

0 - No spinal damage apparent.

1 - Compression (distortion) of vertebrae only.

2 - Misalignment of vertebrae, including compression.

3 - Fracture of one or more vertebrae or complete separation of two or more vertebrae.

Autopsy --- Used to evaluate hemorrhaging.

0 - No hemorrhage apparent.

1 - Mild hemorrhage; one or more wounds in the muscle, separate from the spine.

2 - Moderate hemorrhage; one or more small ($\leq$ width of two vertebrae) wounds on the spine.

3 - Severe hemorrhage; one or more large (> width of two vertebrae) wounds on the spine.

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ways including pulse shape, rate, duration, intensity, and other factors. Failure to fully report these variables has been a major problem in comparing much of the existing scientific literature regarding electrofishing injury (Reynolds 1992). The equipment used in this study was primarily that produced by Coffelt Manufacturing, Inc. of Flagstaff, Arizona. The exception was the electrofishing box designed and built by Harley Leach of Bozeman, Montana referred to as the Leach Box. The waveforms used in this study are illustrated and described (Figure 1).

RESULTS & DISCUSSION

About 900 fish were examined during the course of this research. Sampling was designed to evaluate differences in injury rates due to various factors including variability in electrical waveforms and electrofishing methods, as well as species and size of fish. Although we will focus on results pertinent to these four areas of concern we will also discuss other variables, as well as the physical manifestations of electrofishing injury.

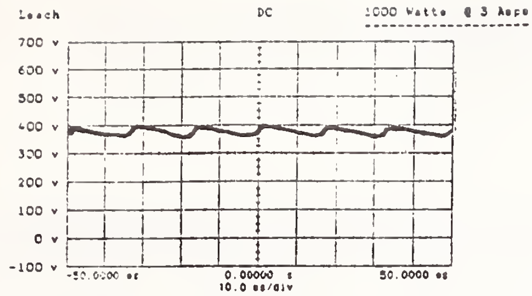
Waveform and Electrofishing Method

Tests conducted on the West Fork of the Bitterroot, Swan, and Bighorn rivers demonstrated that smooth DC and the Coffelt CPS waveforms are much less injurious to rainbow trout than is the conventional 60Hz pulsed DC (Figure 2). In these samples, a total of 248 fish were analyzed. The four sample groups collected with 60Hz pulsed DC showed consistently high injury rates (Table 2) regardless of variations in waveform (square vs. rectified sine), equipment, water conductivity, water temperature, and other variables. The percentage of each of these samples with detectable electrofishing injury ranged from 65 to almost 98 percent. The consistently high percentage of fish suffering Class 3 injuries (23.9 - 30.4%) in all 60Hz pulsed DC samples was an even greater concern.

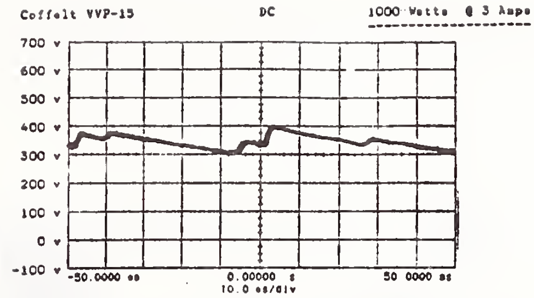
Clearly, the use of 60Hz pulsed DC is highly injurious to rainbow trout and its use should be suspended in rainbow trout waters. A dramatic decline in injury rate was observed when smooth DC and CPS were used (Figure 2, Table 2). The decline in Class 3 injury rates, ranging from 0 to 10.7% depending on the sample, was particularly important.

The average severity rating (ASR) also demonstrated the substantial difference in injury rates between 60Hz pulsed DC and the other waveform types (Table 2). Injury rates using CPS were higher than those from smooth DC, but it is noteworthy that very few injuries from CPS were in the Class 3 category.

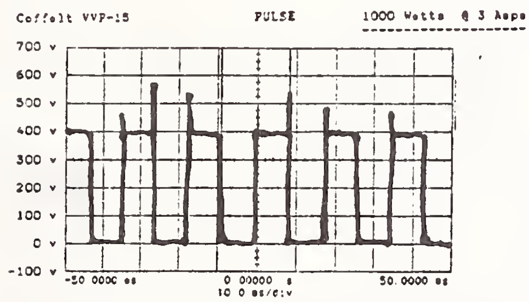
Smooth DC and CPS are the waveform types that should be used to avoid severe spinal injury in rainbow trout. These conclusions are supported by Cowx and Lamarque (1990). This recent review of



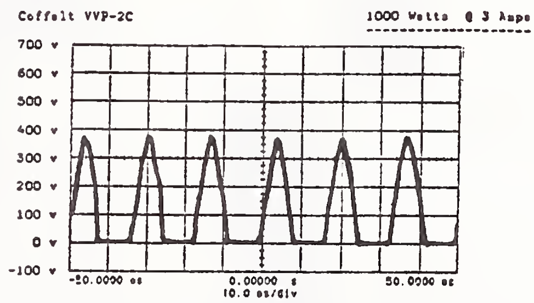
A.) Smooth DC - (Leach)



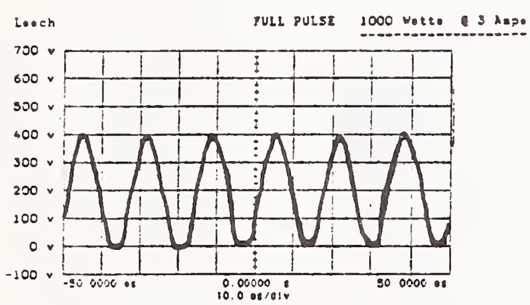
B.) Smooth DC - (Coffelt VVP 15)



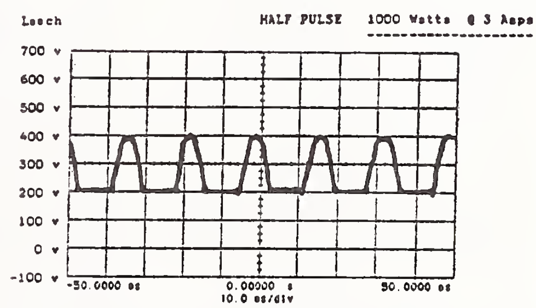
C.) Pulsed DC - 60Hz Square
(Coffelt VVP 15)



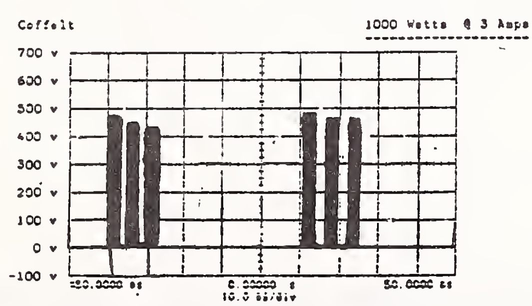
D.) Rectified AC - 60Hz Sine
(Coffelt VVP 2C)



E.) Rectified AC - 60Hz Sine
(Leach - Full Pulse)



F.) Rectified AC - 60Hz Sine
(Leach - Half Pulse)



G.) CPS - (Coffelt Mark 22)

Figure 1. Electrical waveforms generated by the electrofishing units used during this study. Waveform illustrations were obtained with a digitizing oscilloscope at a power output of 1,000 watts and a current flow of 3 amps. (DC=Direct Current; Hz=cycles per second; AC=Alternating Current; CPS=Complex Pulse System).

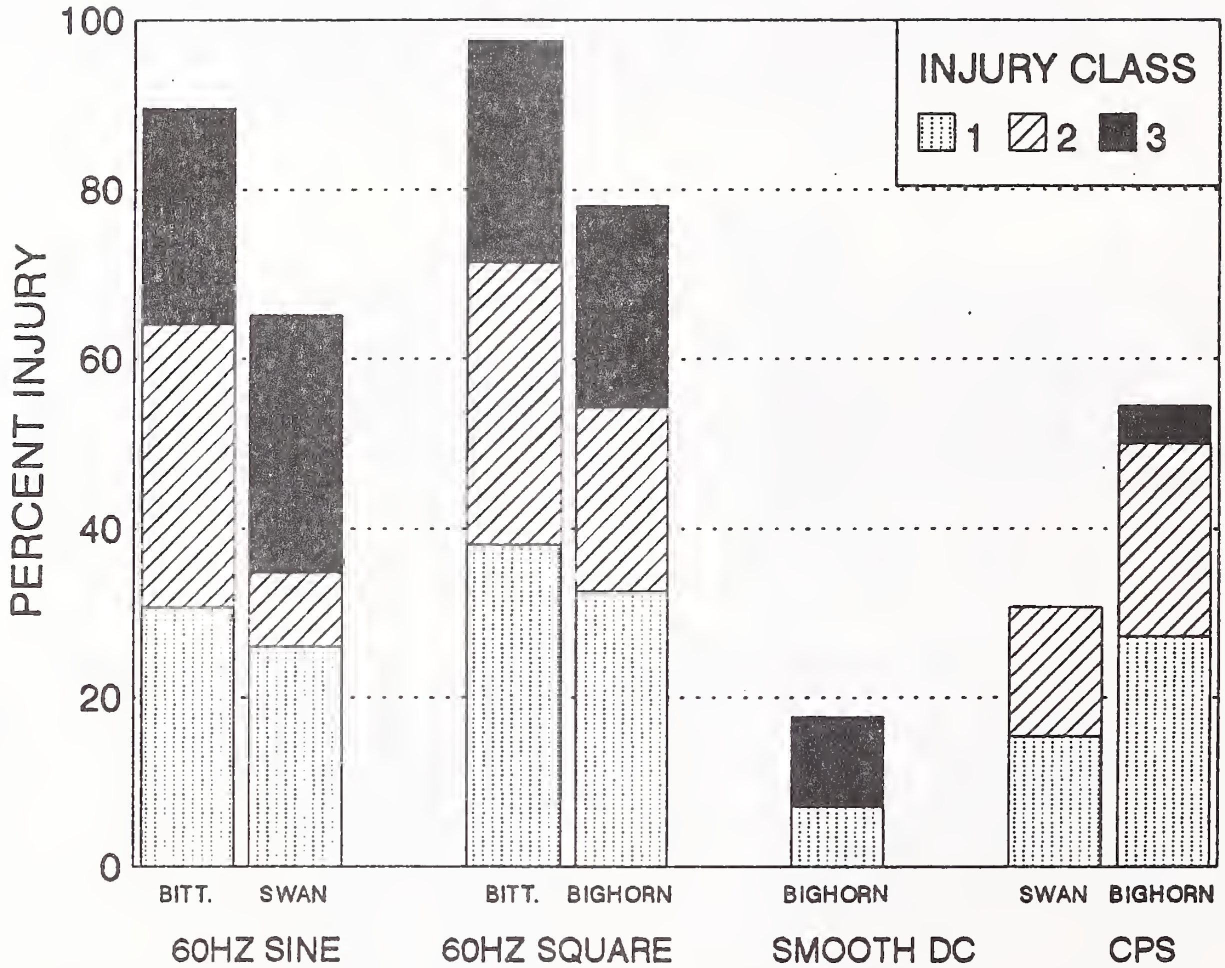


Figure 2. Spinal injury rates, by severity class, of rainbow trout using four different waveforms on the West Fork Bitterroot (Bitt.), Swan, and Bighorn rivers during 1991. All samples were taken with boom-mounted boats and Coffelt electrofishing units. (See Figure 1D, 1C, 1A, and 1G for waveform descriptions).

Table 2. Spinal injury rates (%) of rainbow trout collected using three waveform types on three Montana rivers during 1991. (See Figure 1 for waveform descriptions).

Electro-fisher Model	Waveform Type	River	Sample Size	Injury Rate (%)				Average Severity Rating
				Injury Class			Total	
				1	2	3		
VVP2C	Rectified AC 60Hz Sine	W. Fork Bitter-root	39	30.8	33.3	25.6	89.7	1.74
VVP2C	Rectified AC 60Hz Sine	Swan	23	26.1	8.7	30.4	65.2	1.35
VVP15	Pulsed DC 60Hz Square	W. Fork Bitter-root	42	38.1	33.3	26.2	97.6	1.83
VVP15	Pulsed DC 60Hz Square	Bighorn	46	32.6	21.7	23.9	78.2	1.48
VVP15	Smooth DC	Bighorn	28	7.1	0	10.7	17.8	0.39
Mark 22	CPS	Swan	26	15.4	15.4	0	30.8	0.46
Mark 22	CPS	Bighorn	44	27.3	22.7	4.5	54.5	0.86

electrofishing recommends the use of smooth DC whenever possible.

Numerous researchers have suggested the orientation of a fish in the electric field (Cowx and Lamarque 1990), the time duration of the shock (Whaley et al. 1978), and the intensity of the shock (Kolz and Reynolds 1990) play a role in the rate of spinal injury. We examined a sample of 148 rainbow trout and 150 brown trout collected from the Madison River using the mobile anode method of electrofishing. All fish were taken from the same river habitat over a two-day period using three different waveforms that were alternated every 15 minutes to eliminate environmental variables as a source of bias.

The rainbow trout sampled showed a consistent trend of increasing injury rate and severity with a progression from smooth DC (Figure 1a), to half-pulse (Figure 1f), to full-pulse (Figure 1g). Brown trout samples showed similar results, but injury rates were lower (Figure 3). These results strengthen the earlier conclusion that smooth DC is less injurious to fish than 60Hz pulsed DC waveforms. The ASR values are similar to results of earlier tests (Table 2).

The mobile anode method of electrofishing allows the operator to throw the anode into likely fish habitat and retrieve the anode with the fish following the moving field. An alert dipnetter can usually intercept the fish as the anode reaches the boat and remove the fish from the electric field. Most fish do not become transverse or achieve a state of narcosis in the electric field.

Although research necessary to verify this has not been done we believe that the mobile anode technique applied with smooth DC current is the optimum approach to minimize serious electrofishing injuries. Rainbow trout samples collected from the Bighorn River when smooth DC was employed on a boom-mounted electrofishing boat had an overall injury rate of 17.8% and an ASR of 0.39 (Table 2). Rainbow trout sampled on the Madison River, collected with smooth DC and the mobile anode method, sustained an injury rate of 30.4% with an ASR of 0.43 (Table 3). However, the Class 3 injury rates were 10.7% and 5.4% on the Bighorn and Madison rivers, respectively.

Sample 3E (Appendix B), which was collected from the Bighorn River using smooth DC current and a boom-mounted electrofishing boat, showed an injury rate of nearly 78% with an ASR of 1.24. Because these results indicated an unusually high injury rate compared to other samples collected with smooth DC the sample was repeated (Appendix B, sample 3J). Results of the second sample were more consistent with other smooth DC samples (Table 2, Table 3). We believe that sample 3E was inadvertently collected with a pulsing waveform and thus we did not include it in the comparisons we have presented. However, we were not able to confirm that fact.

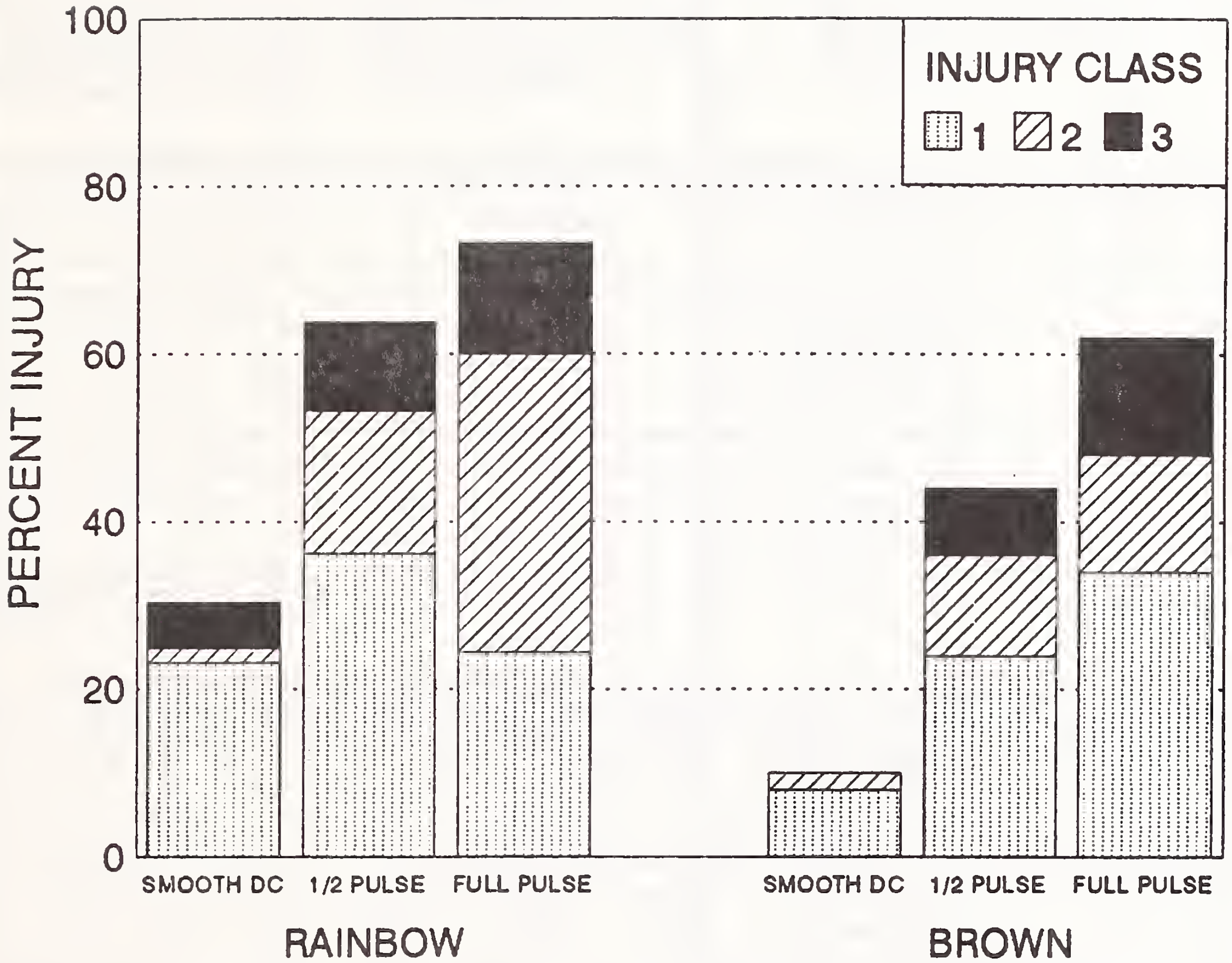


Figure 3. Spinal injury rates (%) by severity class of 148 adult rainbow trout and 150 adult brown trout using three waveforms on the Madison River during 1991. All samples were collected with mobile anode techniques and a Leach electrofishing unit. (Waveforms described in Figure 1).

Table 3. Spinal injury rates (%) of rainbow and brown trout collected with the mobile electrode method, a Leach electrofishing box and three different waveforms on the Madison River. (See Figure 1 for waveform descriptions).

Species	Sample Size	Waveform Type	Injury Rate (%)				Average Severity Rating
			Injury Class			Total	
			1	2	3		
Rainbow	56	Smooth DC	23.2	1.8	5.4	30.4	0.43
Rainbow	47	Rectified AC 60Hz Sine (Half-Pulse)	36.2	17.0	10.6	63.8	1.02
Rainbow	45	Rectified AC 60Hz Sine (Full-Pulse)	24.4	35.6	13.3	73.3	1.36
Brown	50	Smooth DC	8.0	2.0	0	10.0	0.12
Brown	50	Rectified AC 60Hz Sine (Half-Pulse)	24.0	12.0	8.0	44.0	0.72
Brown	50	Rectified AC 60Hz Sine (Full-Pulse)	34.0	14.0	14.0	62.0	1.04

Fish Species

The existing literature on electrofishing injury includes numerous references that species differ in their susceptibility to spinal damage (Cowx and Lamarque 1990). Rainbow trout are widely held to be one of, if not the most susceptible species to damage. In the course of this study, we evaluated rainbow trout, brown trout and arctic grayling in depth as well as cutthroat trout, sauger, and shovelnose sturgeon in less detail.

Results from the side-by-side comparison on the Madison River (Figure 3, Table 3) indicate the injury susceptibility of brown trout is lower than for rainbow. Field observations reported by Montana biologists over a wide variety of conditions for the past 10 years fully support this conclusion. Also, autopsy results generally indicated that brown trout were less prone to hemorrhaging than rainbow trout. Forty-five percent of the total brown trout sample of 150 fish had hemorrhages with only 2% incurring class 3 hemorrhages. Seventy-six percent of 148 rainbow trout had hemorrhages and 6% suffered class 3 hemorrhage. The mobile electrode method of electrofishing, used in combination with smooth DC current, produced only 3 brown trout out of 50 (6%) with minor hemorrhages, for the lowest ASR (0.12) of any of the trout samples collected.

Fluvial arctic grayling, a fish of special concern in Montana, are found at low population levels in the upper Big Hole River. Recovery efforts and ongoing research needs require electrofishing work in the drainage. We collected a sample of 50 arctic grayling 15-18 inches in total length from a spawning run on the West Fork of Hyalite Creek to assess the possible risks electrofishing of grayling may play in recovery efforts. The mobile anode technique and the Leach Box were used. Half the sample was collected on smooth DC and the other half on the half-pulse setting. Only one class 1 hemorrhage and no other evidence of spinal injury were detected. The results corroborate work done in Alaska (Holmes et al. 1990) which concluded that "electrofishing does not have a substantial detrimental effect on grayling populations."

Sampling of westslope cutthroat trout was conducted only incidental to rainbow trout sampling on the West Fork Bitterroot River. A total of 18 cutthroat were taken; injury rates were consistent with rates for rainbow trout similarly sampled. The two species were lumped together in this analysis. At this time, we do not suspect injury rates of cutthroat trout would differ substantially from those for rainbow trout.

Examinations were also made on 8 shovelnose sturgeon, 26 sauger, and 1 walleye taken from the lower Yellowstone River using CPS and 60Hz pulsed DC waveform types on a boom-mounted boat. No injuries were detected by either autopsy or x-ray. Obviously, the x-ray technique did not work to detect spinal injury in sturgeon since they lack a bony skeleton. Further investigation is needed on the effects of electrofishing on warmwater fish species.

Fish Size

There is a general and widely held perception that incidence of spinal injury increases with larger size fish (Cowx and LaMarque 1990). A sample group of 144 rainbow trout, ranging from 8-22 inches in total length, were collected from the Bighorn River to investigate the relationship between fish size and injury. Fish were collected in equal proportions with three different waveform types (smooth DC, 60Hz square-wave pulsed DC, and CPS).

The data did not demonstrate higher rates or severity of injury in longer fish (Table 4). The percentage of fish with class 3 injuries was 16% among fish 8 to 15 inches long and 14% for fish 15 to 22 inches long. Although a single data set provides limited information, it does suggest that longer rainbow trout may not be more susceptible to spinal injuries induced by electrofishing. Cursory observations of samples of 4-8 inch fish found spinal compressions occurred in fish in this size range as well.

In general, the autopsy and the x-ray techniques we used were too crude to conduct injury studies on fish less than 8 inches long. Workers dealing exclusively with small fish should not assume they are not experiencing a spinal injury problem just because it is not externally apparent. Smaller fish may have less calcium in their skeleton and greater flexibility, which results in reduced spinal damage from extreme contractions. However, we believe a portion of the widely held belief that larger fish suffer higher injury rates is due to the impression it makes on a shocking crew when a large fish is damaged, especially since in most waters they occur in relatively low numbers. Damage to small fish would be much less likely to be noticed.

Lamarque (1990) suggests that decalcification of a fishes skeleton as a result of spawning or poor artificial food is likely to increase susceptibility to spinal damage. Additionally, Sharber has suggested (personal communication) that hatchery trout are less susceptible to spinal injury than wild fish. The theory of higher injury rates in larger fish should not be assumed to be true until proven under controlled testing procedures.

Environmental and Equipment Variables

The study was structured to monitor several environmental variables including water conductivity and temperature as well as differences in equipment design such as electrode array and boat type (Appendix B). We hoped to pinpoint by cross-checking differences in sample results factors that might play a role in electrofishing injury.

Water conductivity differences have often been speculated upon as a likely mitigating factor in differing spinal injury rates. Samples we collected with 60Hz pulsed DC from the West Fork Bitterroot, Swan, and Bighorn rivers did not show evidence of

Table 4. Spinal injury rates as a function of fish length for 144 rainbow trout collected from the Bighorn River in Montana during 1991.

Fish Length (Inches)	Sample Size	Injury Rate (%)	Average Severity Rating (ASR)
8.0-8.9	3	67	1.00
9.0-9.9	11	82	1.09
10.0-10.9	11	55	1.09
11.0-11.9	13	62	1.15
12.0-12.9	19	79	1.26
13.0-13.9	13	77	1.54
14.0-14.9	10	70	1.00
15.0-15.9	3	67	1.00
16.0-16.9	3	33	0.33
17.0-17.9	14	71	1.29
18.0-18.9	21	81	1.48
19.0-19.9	14	43	0.57
20.0-20.9	6	50	1.00
21.0-21.9	3	33	1.00
Total	144	67	1.15

substantially differing injury rates (Figure 2) despite widely differing conductivity. The conductivity of those three streams was 35, 177, and 880 umhos/cm on the Bitterroot, Swan, and Bighorn, respectively. This broad range encompasses most conductivities commonly seen in the surface waters of Montana. Although conductivity plays an important role in electrofishing efficiency (Novotny 1974), we conclude it is not a major factor in injury rates.

None of the other variables monitored, including temperature or equipment design, appeared responsible for major differences in injury rate. Water temperatures ranged from 39-64 degrees Fahrenheit during sample collection. Anode arrays included a wide variety of designs from a stainless steel Coffelt electrosphere to a standard triangular aluminum thrown anode to various ring and dropper combinations (Appendix B). Likewise cathode designs were variable, from a small wire diamond to the entire hull of an 18.5 foot long aluminum boat. Generator outputs varied from 300 to 6,500 watts. There are optimal electrode arrangements which increase electroshocking efficiency, and some electrode designs may increase likelihood of injury. However, any such subtle effects in this study were overwhelmed by the obvious detrimental effects of using 60Hz pulsed DC current.

Eggs

Recent research about the effects of electrical fields near recently-deposited trout embryos indicates there is a high potential for damage to embryos at certain stages of development (Dwyer, Fredenberg, and Erdahl in press). Embryos are very susceptible to mortality from electrofishing or mechanical disturbance during the "tender" period about one-third of the way through development. In 46-50 °F water, this was at about day 8 postfertilization for rainbow trout eggs. In one test 95% of eggs buried in artificial redds were killed by a 10-second exposure to CPS at 700 volts. The intensity and duration of the shock may be correlated with mortality.

It is likely that the mechanism which kills the embryos is not the same as the problem of electrofishing-induced spinal injury to fish. A physical rupture of the membranes probably occurs. Nothing currently suggests that pulsed DC, smooth DC or CPS is any more or less likely to kill embryos. Until more is known about this problem, all electrofishing over trout redds should be avoided.

Previous research has produced different conclusions regarding the effect electrofishing has on the unfertilized eggs of female salmonids prior to spawning (Marriott 1973, Cowx and Lamarque 1990). Of course, electrofishing-induced spinal injury may affect a fishes ability to dig a redd or spawn effectively. For this reason, electrofishing during spawning runs should be done with extreme caution.

Physical Manifestation Of Electrofishing Injury

Some discussion of the rating system we used for injuries (Table 1) and its application is warranted. Typically, fish tended to score higher on the autopsy scale (hemorrhage) than on the x-ray scale (spinal damage). On average, the ratings for autopsy were about 0.5 points higher than for x-rays. This is largely because class 2 hemorrhages were fairly common, occurring in up to one-half of the fish from some samples; class 2 spinal injuries on x-ray were fairly uncommon and seldom made up more than 20% of a sample. The choice between class 1 and class 2 spinal injuries, or between a minor compression and a misalignment, was often very difficult. Nonetheless, the level of agreement between the two rating schemes (autopsy and x-ray) was usually quite good. Rating scores were either in total agreement or off by only one point in at least 78% of the fish in every sample.

In cases where scores differed by 2 or 3 rating points, the x-rays and autopsy results were rechecked. In the vast majority of those cases, autopsies showed a class 2 hemorrhage but there were no visible signs of injury on the x-ray. Frequently, these hemorrhages were in the caudal one-third of the fish where compression injuries were hard to detect on x-rays. There were only two fish with injuries which were rated a 3 using one method and a 0 with the other. In one case, the x-ray showed a clearly fractured vertebra but there was no hemorrhage; in the second instance a massive hemorrhage occurred but no spinal damage showed up on the x-ray.

Serious injuries were apparent by either method. In about 40% of the fish rated overall as class 3, the rating was consistent for both autopsy and x-ray. In 85% of all cases, the rating was at least a 2 in one category where the other was a 3.

We chose to combine the two ratings for this report, selecting whichever was the higher, because we believe it is a more accurate reflection of the injury inflicted on an individual fish than use of only one. The average severity rating (ASR) accounts for these variables in summarizing injury rates within a sample.

It would be logical to argue that spinal injuries apparent on x-rays are of greater long-term consequences to the fish than are hemorrhages. We would not dispute this statement, but it has not been demonstrated. In the short term, hemorrhaging may be more significant to a fishes health and well-being than spinal injury.

Controls

We examined x-rays from 104 control fish representing four sample groups; 50 of those specimens were autopsied. None of the fish had been previously electrofished. Spinal deformities can result from factors other than electrofishing such as physical injury from predators or genetic or dietary deficiencies. The

first control group was 50 adult wild rainbow (16-20 inches long) taken from a spawning trap at Willow Creek Reservoir near Harrison, Montana. Two fish had fused vertebrae from natural abnormality. Nineteen control fish from a domestic hatchery strain at the USFWS Fish Technology Center in Bozeman included 8 fish (42%) with spinal fusion of 3-12 vertebrae. Two other control lots of 19 and 16 wild rainbow trout of mixed sizes (8-18 inches long) captured by gill-net in Cliff and Ulerys lakes, respectively, showed no abnormalities. It appears, based on limited data, that the natural occurrence of spinal fusion and deformities in wild fish is fairly rare, but may be high in some lots or strains of hatchery fish. Natural spinal deformity usually consists of the compaction and fusion of 2-12 vertebrae. The fused area is frequently heavily calcified and the spine inflexible throughout the section. Misalignment, either dorsal or lateral, is not common in these natural deformities.

Autopsy of the control fish from Willow Creek Reservoir was conducted to perfect techniques and assess hemorrhaging in unshocked fish. Two fish (4%) had class 1 hemorrhages. However, these fish had been hand-stripped of their eggs prior to autopsy and it is likely that the hemorrhages observed (both on the caudal peduncle) were a result of that activity.

Autopsy of control fish revealed that 3 types of "bleeding" were common in fish that were not electrofished. These conditions were classified as lateral, intervertebral, and subvertebral (Figure 4). We found that control specimens had an average of 6.6 visible lateral hemorrhages (range 0-18), 6.2 intervertebral hemorrhages (range 0-14) and subvertebral bleeding from the aorta was apparent in 85% of the specimens. Some analysts may mistake these hemorrhages for electrofishing-caused injury, when in fact, they do occur with frequency in unshocked controls.

Autopsies

A total of 693 trout that had been electrofished were autopsied, x-rayed, and included in the computerized database (Appendix B). These 693 trout had a cumulative total of 484 class 1 hemorrhages, 221 class 2 hemorrhages, and 64 class 3 hemorrhages. The relative frequency and location of these 769 injuries is highest at 60-64% of total fish length (Figure 5). Spinal hemorrhages occurred on 328 of the 693 fish (47%). Most of the fish had multiple hemorrhages. Of the 328 fish with hemorrhages there were 118 (36%) with a single hemorrhage, 83 (25%) with two, 55 (17%) with three, 38 (12%) with four, 18 (5%) with five, 12 (3%) with six, 3 (1%) with seven, and one fish with eight hemorrhages along the spine.

Individual hemorrhages of lower severity had a tendency to be located on one side of the spine only. Of the 484 class 1 hemorrhages, there were 235 (49%) on the left side and 189 (39%) on the right side. Only 60 (12%) were visible at the same location on both sides of the fish. Autopsy procedures that involve only one

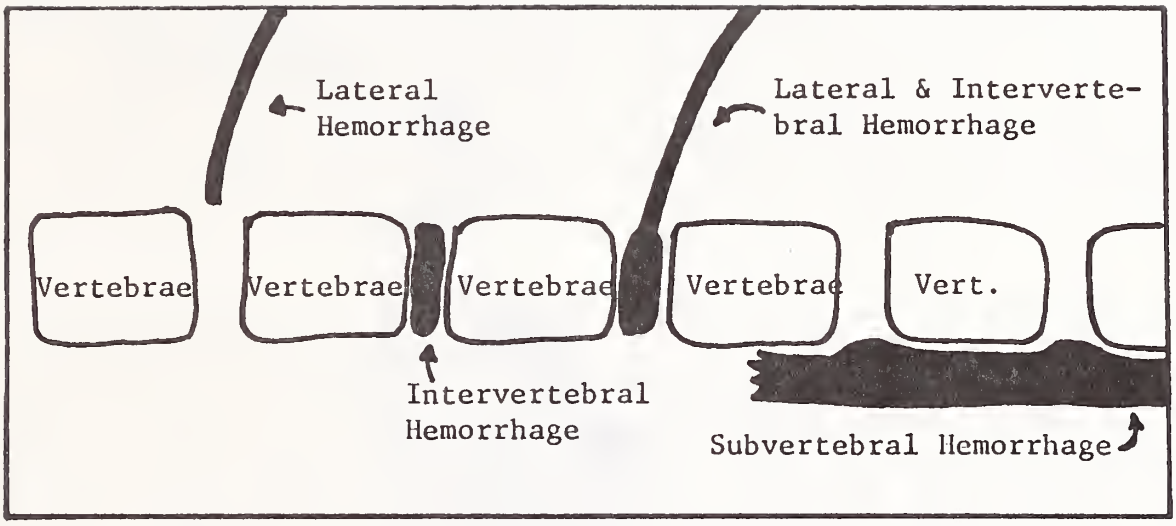


Figure 4. Illustration of lateral, intervertebral, and subvertebral hemorrhaging. This type of hemorrhaging was not only associated with electrofishing injury but occurred in control specimens as well.

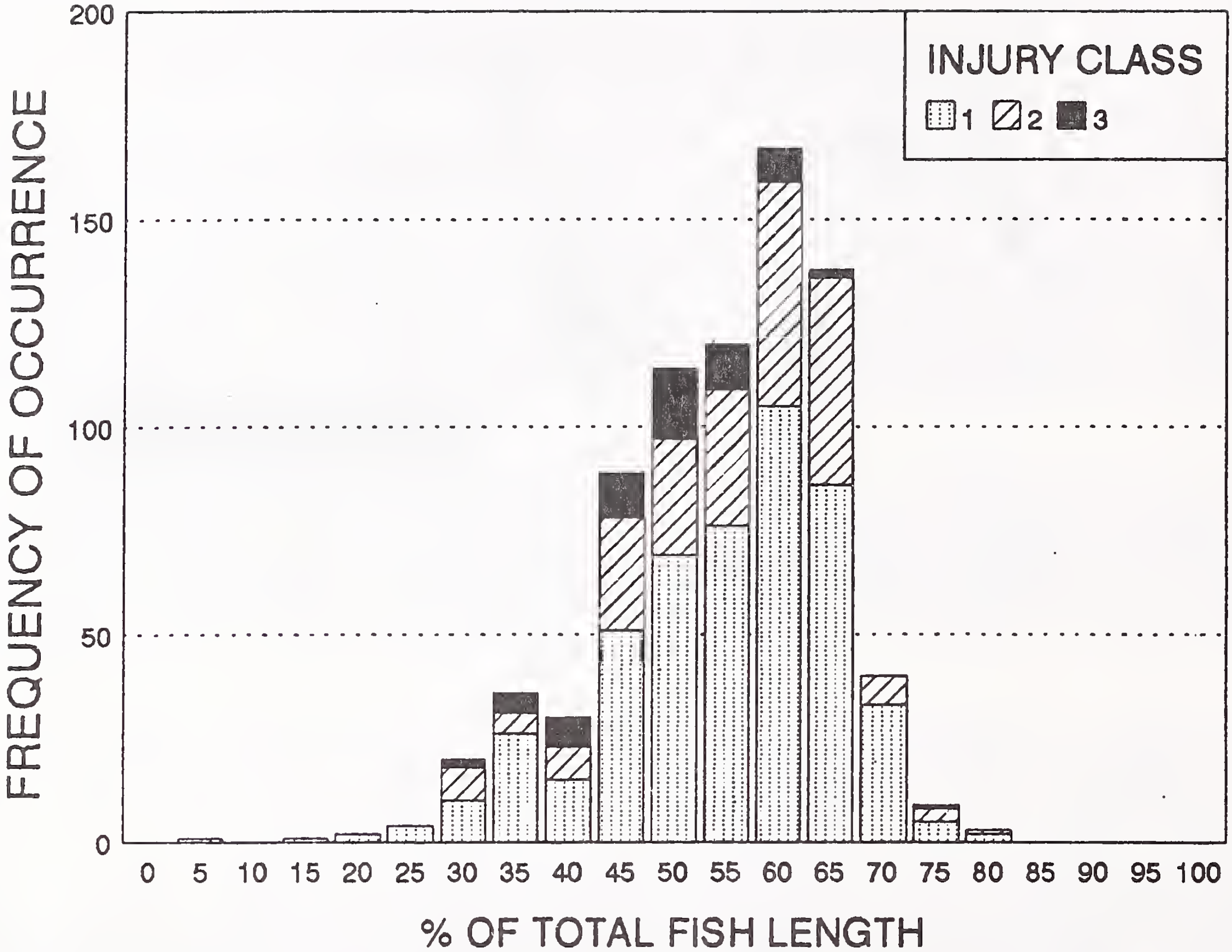


Figure 5. Frequency and location of 769 spinal hemorrhages by injury class as detected by autopsy in a sample of 693 rainbow, brown, and cutthroat trout collected by a variety of electrofishing methods. Each hemorrhage was assigned one point location (its' center) regardless of size.

side of the fish fail to detect a high proportion of minor spinal hemorrhages. Of the 221 class 2 hemorrhages, we found 63 (29%) on the left, 79 (36%) on the right, and 79 (36%) on both sides. Only 9 (14%) of the 64 class 3 spinal hemorrhages we examined were on the left, 7 (11%) were on the right, and 48 (75%) were visible on both sides at the same location. Contusions of increasing severity apparently spread across the width of the fish as well as along its length. The vast majority of injuries are concentrated in the mid-section of the fish. In fact, 83% of Class 1, 89% of Class 2, and 88% of Class 3 hemorrhages occurred in the areas between 40 and 70% of the total length of the fish. The median area for class 1, 2, and 3 injuries, respectively, was 60, 61, and 52% of the total length.

A random group of ten rainbow trout were measured from x-rays to determine the position (as a % of body length) of various body parts in order to assign some points of reference to the above findings. There was very little variation from fish to fish. Typically, the first anterior and the last caudal vertebra were located at 14% and 84%, respectively, of the total body length (Figure 6). Thus, 70% of the total fish length includes the spinal column. According to published literature, rainbow trout typically have 60-66 vertebrae and brown trout 56-61 (Scott and Crossman 1973). The specimens we examined fell within this range. The 30th vertebrae (shaded in Figure 6) was typically between 45 and 49% of the total length, averaging 47%. The leading edge of the dorsal fin was inserted at an average 42% of total length while the anal fin was inserted at 65% of total length.

The vast majority of spinal hemorrhaging occurred between the front of the dorsal and rear of the anal fin, with the overall mean location of all hemorrhages at a point corresponding with 57.5% of total fish length. Hemorrhages were detected at nearly every position on the spine, from 19-82% of total fish length.

The most noticeable trend in the relationship between hemorrhage severity and location was the tendency for Class 3 hemorrhages to be further forward on the fish than Class 1 or 2 hemorrhages (Figure 5). Indeed, the most severe hemorrhages (Class 3) were located near the exact middle of the fishes' total length, which corresponds to the area between the rear edge of the dorsal and front edge of the anal fin.

Typically, Class 3 hemorrhages were characterized by dark red hematoma at least 2 cm in diameter or larger. Frequently, the vertebra at the center of this bruise was visibly fractured (Figure 7). When the spinal column was filleted out of the fish and then physically bent, it would usually break through the fractured vertebra. The physical separation of ribs from the skeleton was relatively uncommon and observed only a couple of times.

A phenomenon not previously described by other researchers was the presence of alternating hemorrhages from side to side. An example occurred in one fish with six hemorrhages on the spine.

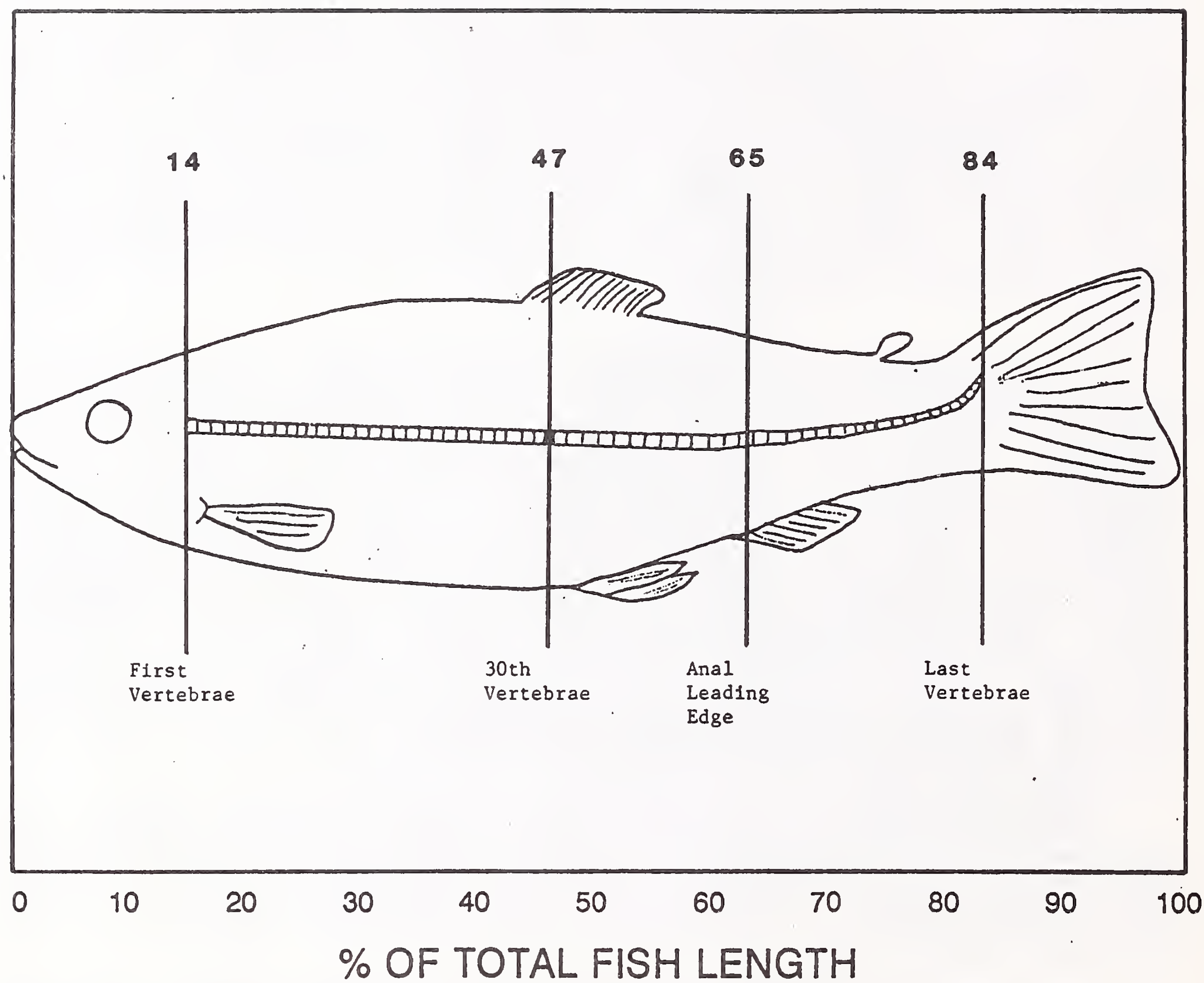


Figure 6. Illustration to scale of a typical rainbow trout showing the placement of fins in relation to vertebrae. The 30th vertebrae is shaded.

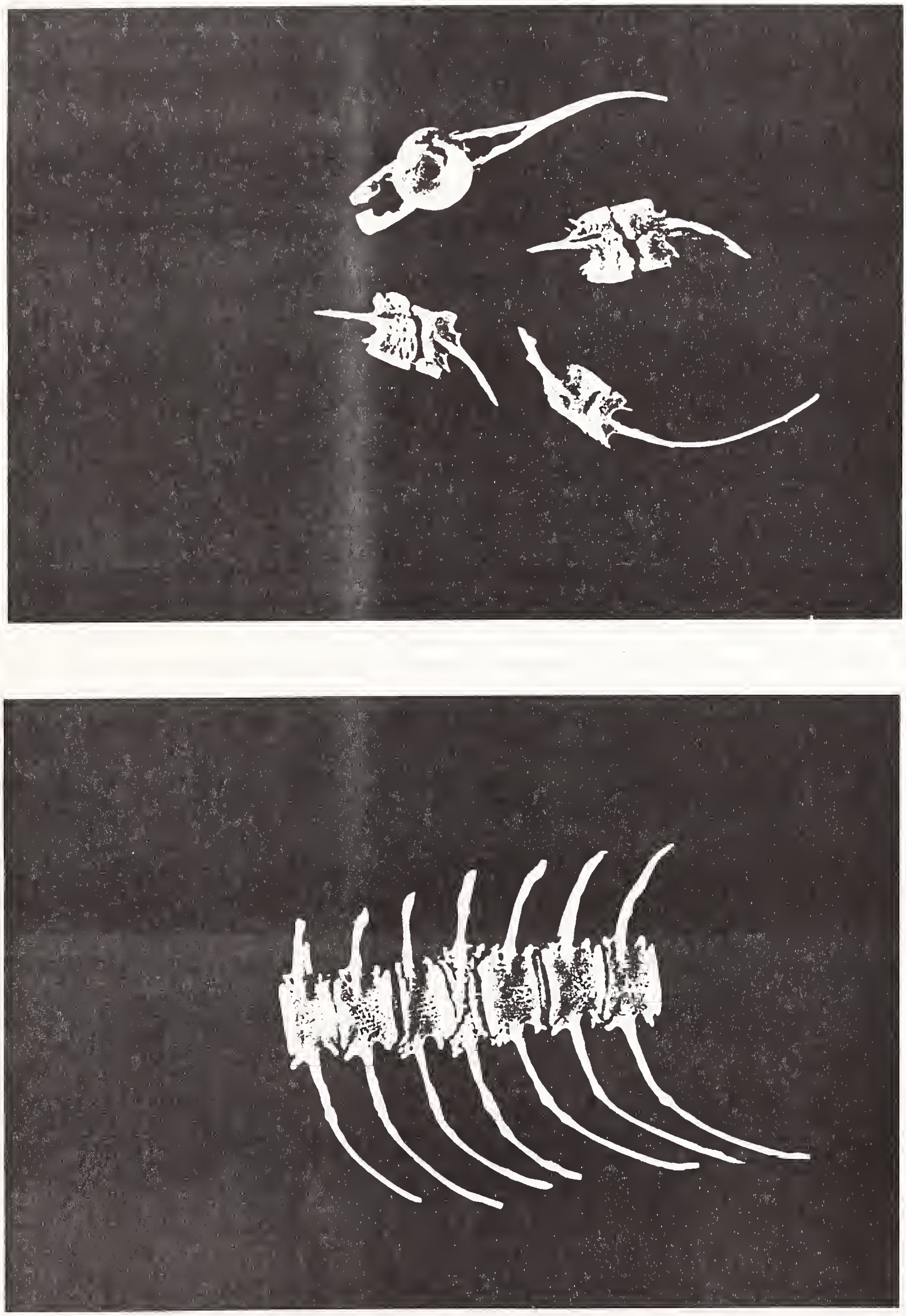


Figure 7. Freshly fractured vertebrae from an adult rainbow trout (top photo) and a spinal section including a crushed vertebra that healed (center of bottom photo). Injuries occurred as a result of electrofishing.

Hemorrhages on the left side were visible at 43, 54, and 64% of the total 18.9 inch body length and on the right side at 36, 49, and 59%. Thus, this fish had a hemorrhage every 1-1.5 inches along the spine in a left-right alternating pattern. Alternating hemorrhages were commonly observed in fish with multiple hemorrhages.

While the frequency and severity of spinal hemorrhage varied by sample group as a consequence of the waveform used and other factors, there were no readily discernible differences between the type of injuries inflicted. It is evident that tissue damage and hemorrhage occurs as a result of torn musculature and blood vessels. It is described by Cowx and Lamarque (1990) as being the result of "violent contractions produced simultaneously by the current of both sides of the fish body following direct excitation and hyper-reflexivity." One would not expect to see differences in the nature of the injuries, only in the degree. Hemorrhage data by sample is summarized (Appendix B).

X-Rays

The assessment of x-rays was used as the sole determination of injury to the spinal column, augmented by autopsy observations in a few questionable cases. The percentage of fish, by sample group, exhibiting class 1, 2, and 3 spinal injuries is compiled (Appendix B). As with the autopsy data, there were no obvious differences in the types of spinal injuries observed between sample groups, only differences in severity and frequency.

In total, we enumerated 2,647 vertebrae that were classified as injured, an average of 11.3 injured vertebrae for each of the 234 injured trout. Of that total, 89% were classified as class 1, 8% class 2, and 3% class 3. Figure 8 shows the frequency by vertebra of spinal injury occurrence for the combined sample group of 693 trout. The highest incidence of spinal injury was recorded at vertebra number 32 where 167 of the 693 trout (24%) showed evidence of spinal damage. Coincidentally or not, vertebra number 32 is near the exact midpoint of the spinal column in a normal rainbow trout which has 60-66 vertebrae.

There was a tendency for the more severe vertebral injuries to be posterior to the midpoint of the spine (Figure 8). Eighty-one percent of class 3 injuries to vertebrae were between vertebrae number 31 and 45. These observations closely parallel those of Sharber and Carothers (1990) who found most abnormalities occurred between the 29th and 45th vertebrae. There were very few spinal injuries and no class 3 injuries anterior to vertebra 18 or posterior to number 44. Sharber and Carothers (1990) found 82% of all spinal damage occurred between the 14th and 53rd vertebrae.

Spinal injuries, in general, as detected by x-ray, tended to be further forward than the overall location of hemorrhages located by autopsy (Figure 9). There was a trend toward occurrence of hemorrhages in the rear half of the fish that often did not result in noticeable spinal injury detectable from x-ray.

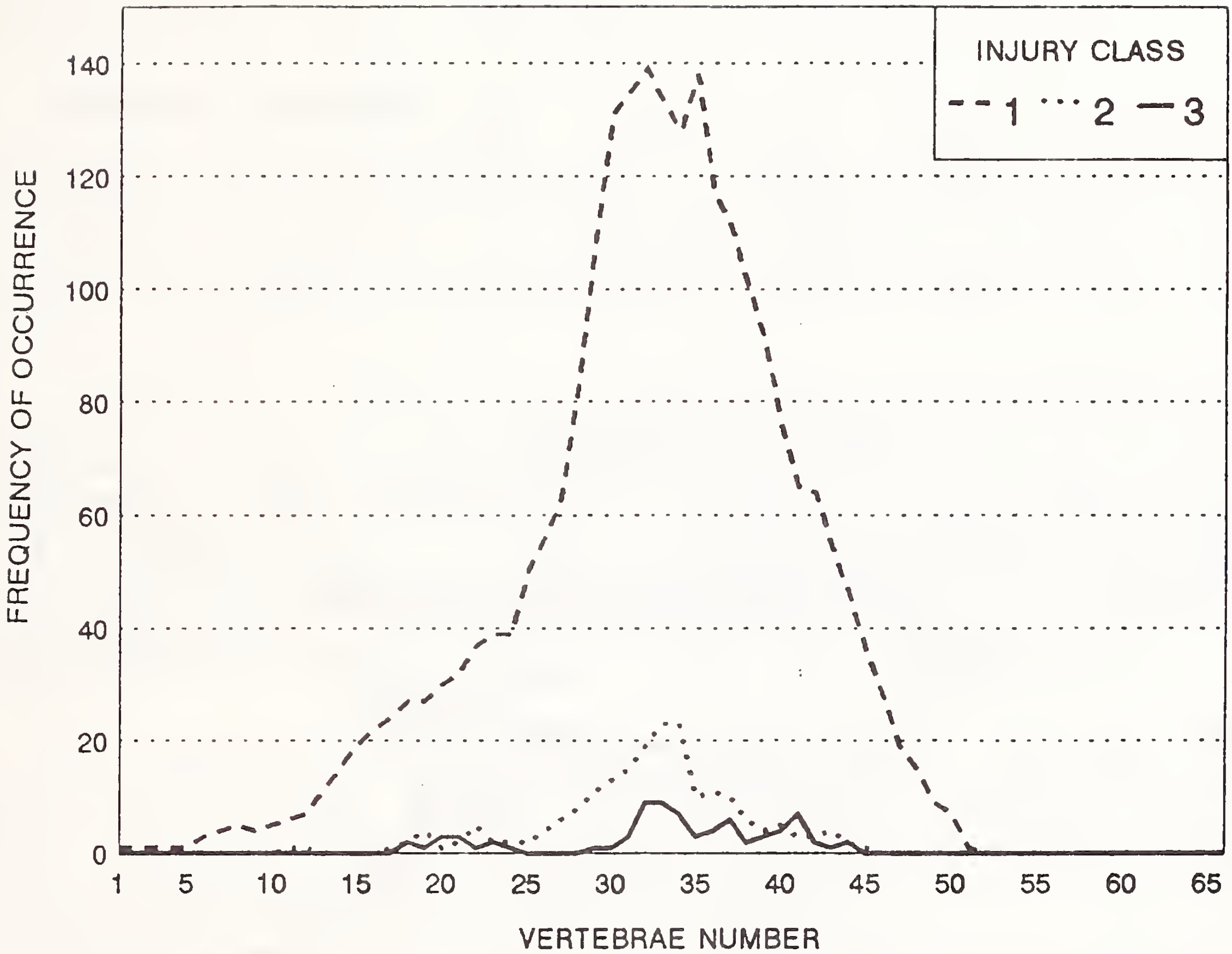


Figure 8. Frequency and location of 2,647 injured vertebrae by injury class as detected from x-ray of 693 rainbow, brown, and cutthroat trout collected by a variety of electrofishing methods.

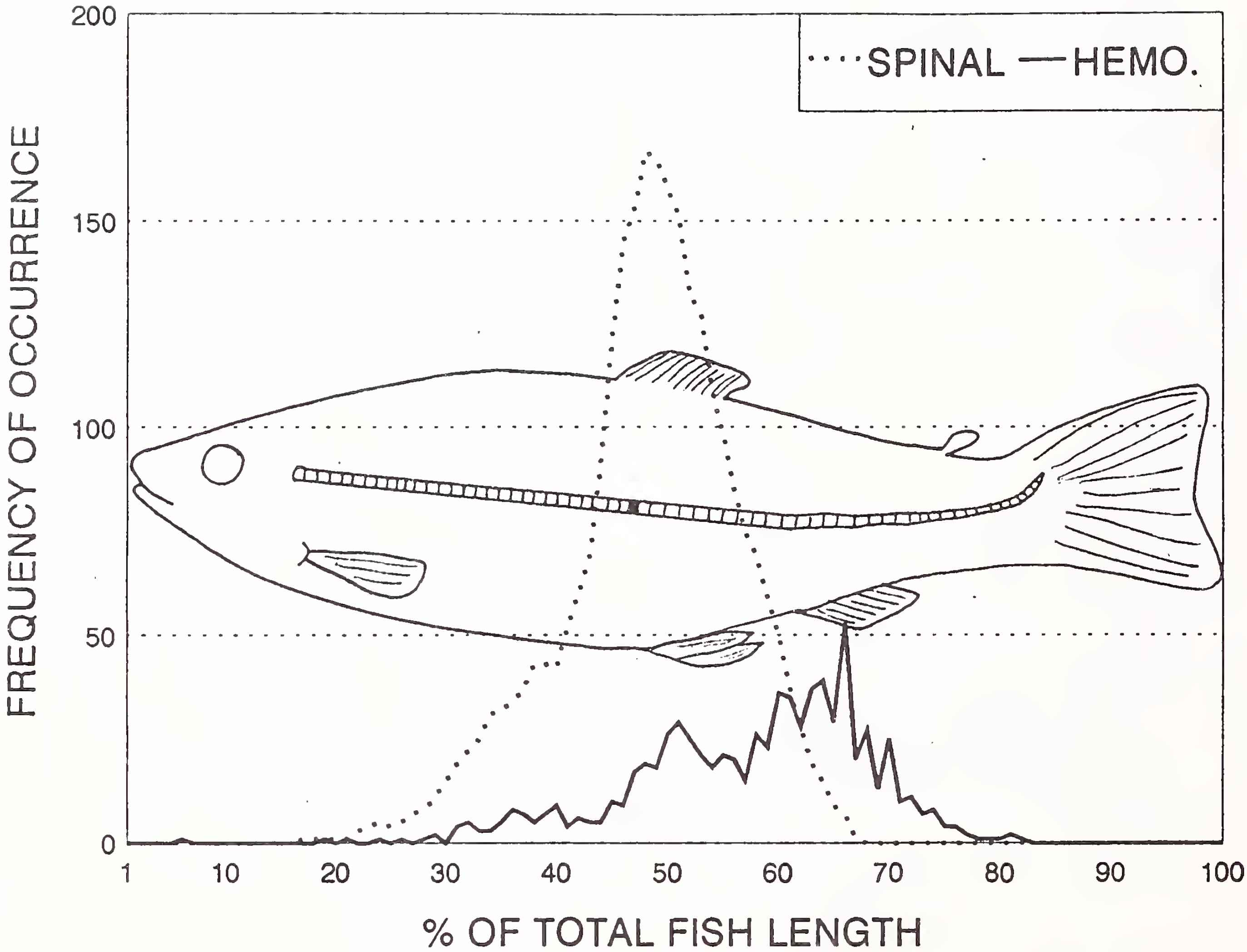


Figure 9. The relative location and frequency of 769 hemorrhages (solid line) and 2,647 injured vertebrae (dotted line) in a sample of 693 rainbow, brown and cutthroat trout collected by a variety of electrofishing methods.

There was, however, close agreement overall between autopsy and x-ray on the location of Class 3 injuries. About three-fourths of all severe injuries (Class 3) occurred in the region of the fish between the rear insertion of the dorsal fin and front insertion of the anal fin.

A total of 125 fish that were x-rayed suffered only Class 1 compression injuries (18%). Typically, these involved the compression of 5-20 vertebrae with no misalignment apparent. In cases where the compression was strong enough to cause misalignment of vertebrae (Class 2), it normally involved a series of 2-5 misaligned vertebrae in the midst of a Class 1 compression. Class 2 spinal injuries occurred in 49 fish (7%).

Frequently, a severe spinal compression caused vertebrae to be crushed or fractured (Figure 7). This occurred in 60 of the sample fish (9%). These injuries were nearly always in the midst of severe spinal compressions and were usually flanked by Class 2 and Class 1 compressions. Multiple compressions were not uncommon, with 2 or even 3 separate areas of spinal damage. In such cases, it was common for the areas of most severe damage to be centered at about one-third and two-thirds of the total length of the fish, rather than close to the midway point.

Old injuries that had healed were common in some sample groups, particularly from the Bighorn River. Typically, such injuries were evident on the x-rays due to heavy calcification and fusion of 2-20 vertebrae. Usually, such injuries were readily distinguishable from natural deformities due to misalignment of the spine at the point of the injury.

Brands

There has been limited discussion in the literature regarding the occurrence and significance of "burn marks" on fish as a result of electrofishing (Holmes et al. 1990, Jackson 1955, Cowx and Lamarque 1990). We will use the term "brands" to more accurately describe this phenomenon. We examined a sample of fish from the Bighorn River to determine the significance of branding.

We collected 152 adult-sized rainbow trout from the Bighorn River, using a variety of waveforms. At the time of capture, all fish were examined for brands and those with such marks were adipose-clipped. The brand marks were observed to disappear shortly after death. According to the authors of a study conducted in Alaska, the brands disappeared from live fish held 96 hours in a holding pen (Holmes et al. 1990). A total of 39 branded fish (26%) were observed in the 152-fish sample. Only one of those 39 fish did not suffer an electrofishing injury, and it was noted in autopsy to have a slightly crooked spine that likely resulted from an electrofishing compression that went undetected by x-ray. In the unbranded sample, there were 57 fish (50%) that were classified as uninjured by both autopsy and x-ray (Figure 10). The average severity rating (ASR) for branded fish was 2.00 and 25 of the 39

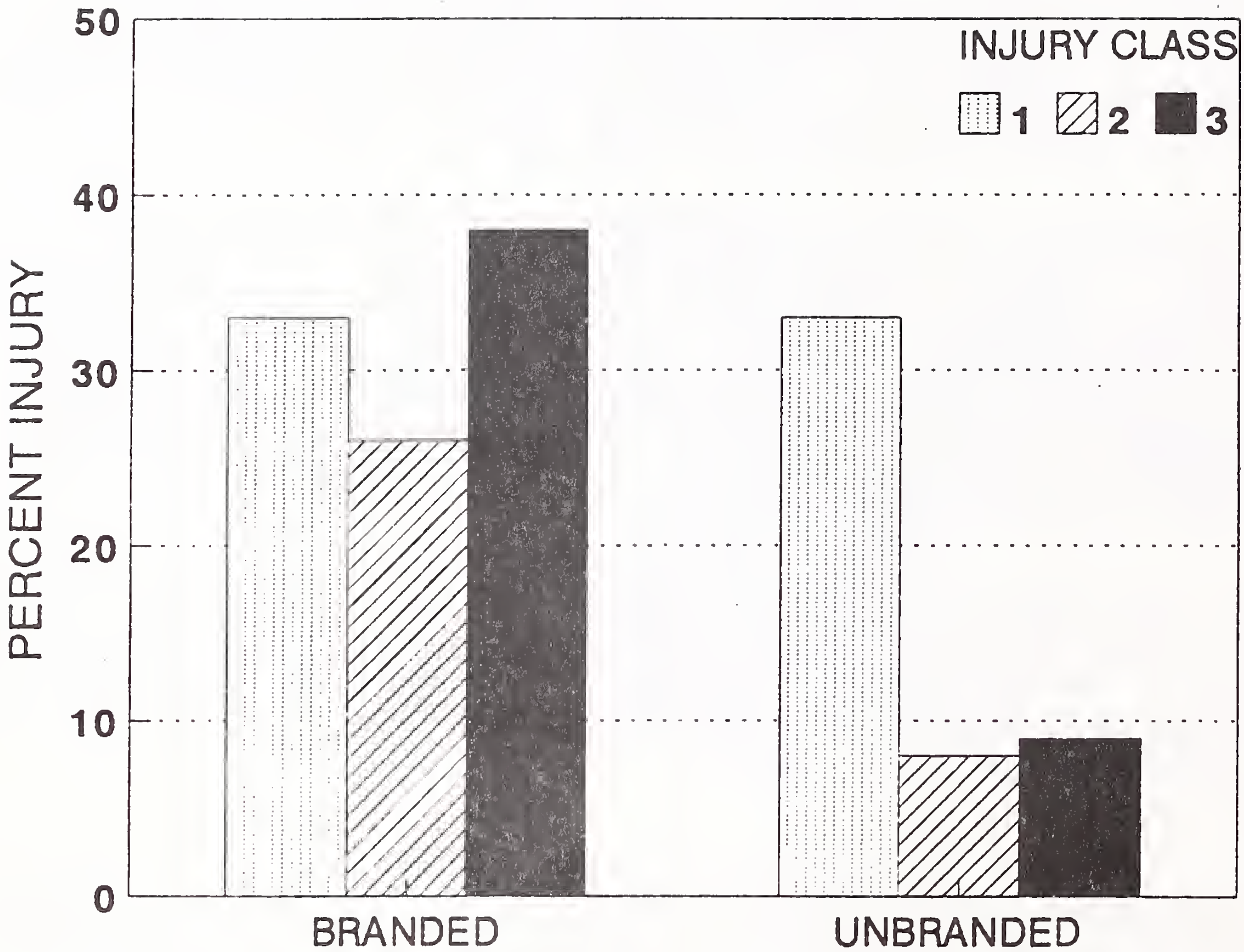


Figure 10. Spinal injury rates (%) by severity class for 39 adult rainbow trout with external "brands" and 113 without "brands" collected by electrofishing from the Bighorn River in Montana during 1991.

(64%) suffered Class 2 or 3 injuries. The ASR of unbranded fish was 0.75 and only 19 of 113 (17%) suffered Class 2 or 3 injuries. In this instance, a strong relationship existed between the presence of brands and serious electrofishing-induced spinal injury. The incidence of minor injury (Class 1) was identical (33%) in both samples.

The strong correlation between incidence of serious spinal injury and appearance of brands in these samples needs further investigation. We believe that brands result from erratic chromatophore stimulation as a result of injury to the nervous system. We did not investigate the relationship between brand location and injury location, but there should be a correlation between the two as Cowx and Lamarque (1990) suggest. The absence of brands in sampled fish does not indicate that injury is not occurring. But, the presence of brands on electrofished specimens should be viewed immediately as cause for concern about spinal injury.

CONCLUSIONS AND RECOMMENDATIONS

Electrofishing Efficiency

Observations from these studies on Montana waters indicate that with a boom-shocking sampling boat, 60Hz pulsed DC is probably the most efficient waveform for catching fish under many circumstances. However, its future use in electrofishing salmonids, and in particular rainbow trout, will be very limited because of the unacceptably high injury rates it produces. Consequently, the challenge will be to deploy more acceptable waveforms (e.g. smooth DC and CPS) to the optimal extent.

The pioneering work of Dr. Novotny in 1974 has withstood the test of time and most of his recommendations remain sound today (Novotny and Priegel 1974). There are numerous factors which influence electrofishing efficiency including: water conductivity, water temperature, depth, current velocity, turbidity, instream cover, operator proficiency, electrode design, power source, experience of the crew, fish species, fish size, and even weather. There are precise methods to evaluate electrofishing efficiency (Cross 1976). However, most electrofishing applications are stream-specific and will vary even during the same day. Biologists in the field cannot settle on one tried and proven method, but have to adjust to changing conditions. In that regard, knowledge of electric fields and how to account for changing conditions is a necessity. The neophyte as well as the seasoned biologist should reread Novotny's work as often as possible to reinforce those tenets. The best available treatise is now a chapter by Novotny in the book <u>Fishing With Electricity</u> (Cowx and Lamarque, 1990). What follows is a brief summary of some of that information as it applies to this study.

In medium to high conductivity waters (200-1,000 umhos/cm),

the challenge is to put enough power into the water. Typically, this is limited not by the electrode design but by the size of the generator. Small generators (less than 2,500 watts output) are generally insufficient under most circumstances to meet the power criteria for efficient electrofishing. Fish in the field will be captured but the field range is small. The simple rule is "bigger is better." It is better to use a large generator (4000 watts or larger) and turn down the power to a lower level than it is to overextend a small unit. Many times electrofishing is inefficient due to an insufficient power supply and no amount of equipment tinkering will change this. This is particularly true when using CPS or especially smooth DC which demands greater power due to the high duty cycle.

In the low conductivity waters (less than about 200 umhos/cm) frequently found in western Montana, the problem is getting the power into the water. A 2,500 watt generator is probably adequate. In theory, the solution is to maximize surface area of the anode or step up the voltage. New and innovative designs to incorporate large electrode surface area while minimizing drag and dipnetter interference are required to overcome this dilemma. Again, follow the rule "bigger is better."

All of the field observations we have conducted to date indicate a very different response by fish to the CPS and the smooth DC waveforms. Without a doubt, smooth DC provides the greatest electrotaxis. For that reason, it is the only reasonable option for a throwable anode operation. In a boom boat, straight DC will provide a relatively smaller field, but fish in this field will come directly to the electrode and swim there for up to several seconds making dipnetting easy. This provides for highest efficiency in situations where the water is turbid or turbulent or during night operations. However, in large and relatively slow-moving or clear waters where fish have a tendency to exhibit avoidance, then CPS may provide a better choice. The effective field dimensions of CPS will be greater (given the same amount of power), but the fish exhibit a much more active behavior in the CPS field than under smooth DC. They will dart through the anode area at high speed, frequently making a large loop and returning from a different direction. They often still end up at the electrode but the challenge to the dipnetters is much greater. The researchers must experiment with a variety of operations to maximize efficiency on their particular body of water.

Use of the half pulse and full pulse modes on the Leach Box requires special mention. In the Madison River, using a mobile anode in a series of riffle-pool habitats, we measured the capture efficiency of all three waveforms. We averaged 1.13 trout/minute on straight DC, 1.10 trout/minute on half-pulse, and 1.08 trout/minute on full pulse. While more fish were observed on half-pulse and full-pulse, the decreased electrotaxis and increased narcosis precluded any capture advantage and injury rates on the pulse waveforms were clearly unacceptable. Without controlled testing, one should not assume that the observations of relative

efficiency of different waveforms are accurate.

Literature Review

During this study over 130 papers, theses, books, and reports dealing with electrofishing physiology, methods, and equipment were reviewed and assembled into a library. Copies of this reference list and/or individual papers will be made available upon request.

As Reynolds (1992) points out, "mortality and injury rates are the result of a complex mix of factors, and few studies have adequately standardized, or documented, these factors." In this report we have attempted to systematically fill some of those gaps. However there are myriad combinations of physical, chemical, and mechanical variables and it is impossible to answer all of the questions.

Electrofishing Guidelines

What follows is a set of recommendations for electrofishing trout in Montana based on the present state of knowledge of the subject of electrofishing injury. They are presented in table format (Table 5).

Some of these guidelines admittedly involve judgment calls, based on experience to date, and may need to be modified as more information becomes available. However, collectively these recommendations will go a long way toward solving the problem of electrofishing injury.

As biologists, we must recognize our ethical responsibility to minimize injury to the species and populations we are studying. High rates of injury affect only the quality of the information we collect by biasing estimates, and potentially may reduce the viability of certain populations. In addition, our credibility in both the scientific community and with the public we serve depends on the maintenance of high professional standards. At this time we do not believe that the problem of electrofishing injury to certain salmonids can be totally eliminated using conventional equipment. Our goal is to minimize injury rates by optimizing the combination of equipment, conditions, and knowledge which are required to conduct electrofishing surveys in the state of Montana.

Table 5. Montana Electrofishing Guidelines.

PARAMETER	RECOMMEND	AVOID
Pulse Rate	30 Hz or less	40 Hz or more
Pulse Duration	5 milliseconds	10 milliseconds or >
Pulse Shape	Smooth DC - Best CPS - Second Choice Square - 3rd Choice	Rectified Sine Capacitor Discharge AC
Voltage	High Conductivity = use low voltage Low Conductivity = use high voltage	
Shocker Box	Coffelt Mark 22M Coffelt Mark 22 CPS Coffelt VVP 15 (smooth DC or low pulse rates) Leach/Fisher (smooth DC only)	Coffelt VVP2C Coffelt VVP2E Leach/Fisher Pulse
Generator	Low Conductivity (<200 umhos/cm) 2,500W or > High Conductivity (>200 umhos/cm) 5,000 W or >	Inadequate power plant.
Electrode	Bigger is Better - Always use largest possible anode except in highest conductivity water (800 umhos/cm or >) Always maximize cathode size, in metal boats use the boat.	Small point anodes such as a single dropper. Never use small cathode.
Method	Mobile Anode - Best	Never allow fish to lie in field.

Table 5 (Cont'd.)

PARAMETER	R E C O M M E N D	A V O I D
Intensity	Turn power down to the lowest level you can get by with.	Overkill.
Brands	Look for brands. If numerous turn power down.	Branded fish are an indicator of spinal injury.
Fish Species	Most Susceptible to spinal injury - Rainbow Trout, Cutthroat Trout, Brown Trout Least Susceptible - Arctic Grayling, Warmwater Spp.	Never assume fish are not being injured based only on external appearance.
Fish Size	Be more cautious with large fish even though the evidence is mixed on susceptibility to injury.	Do not assume small fish are immune to spinal injury.
Environmental Variables	Record water temperature and conductivity and adjust methods accordingly.	Do not ignore water conditions.
Eggs	Avoid shocking spawning females and areas with redds.	Assume eggs in redds have potential to be damaged.
Crew	Use the best-trained crew available. Avoid multiple-dipping into the field and other factors that will stress fish.	Avoid an untrained crew. Never electrofish under conditions that are marginal or hazardous for you or the fish.

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Electrofishing Injury Study
Sampling Protocol

All sampling and injury assessment will follow the same standardized procedure in order to minimize variations due to human interpretation and error. Prior to saampling, we will set up and test the system and fill out the attached "Field Survey Cover Sheet." This provides a systematic way of recording information on most of the known variables.

With that completed, field sampling may begin. Fish collected should be immediately placed in a high concentration solution of anaesthetic which will immobilize them and cause death through asqhyxia.. Once dead fish should be marked and placed on ice for transport to the lab. Within 24 hours of collection, fish should be either frozen or x-rayed and autopsied.

Autopsy and x-ray will follow this procedure:

Internal Hemorrhage

Fish should be killed and either frozen or held on ice to allow clotting in blood vessels. Fish should not be filleted immediately after death because fillet-related bleeding will mask injury-related hemorrhages. Fillets should be smoothly cut close to rays and spine, through the ribs and back to the caudal peduncle. Photgraph the left side of fish with the inside of both fillets up; color slides are best for follow-up evaluation. Rate each hemorrhage in the muscle mass as follows:

- 0 - no hemorrhage apparent
- 1 - mild hemorrhage; one or more wounds in the muscle, separate from the spine
- 2 - moderate hemorrhage; one or more small (≤ width of two vertebrae) wounds on the spine
- 3 - severe hemorrhage; one or more large (〉 width of two vertebrae) wounds on the spine

Categorize hemorrhage position by measuring from the nose to the center of the hemorrhage. Include side of fish. (e.g. 13.3 B = hemorrhage on both sides 13.3 inches from nose).

Spinal Damage

Fish should be dead or anesthetized to insure good resolution on X-ray negatives. Photgraph the left side of each fish, positioning it to include all vertebrae. X-rays of two or more fish per plate will save money. Record the position of every affected vertebrae, counting the first separate vertebrae behind the head as number 1. Rate the damage to the spine as follows:

- 0 - no spinal damage apparent
- 1 - compression of vertebrae only
- 2 - misalignment of vertebrae, which may include compression
- 3 - fracture of one or more vertebrae or complete separation of two or more vertebrae

Appendix Table A1. Sampling protocol.

Note: Separation of ribs from the spine in a separate category.

The attached "field/lab sample analysis" form will be used for all sample processing. Any and all pertinent observations in addition to the above should be recorded. A series of reference photos of category classes will be developed.

X-ray techniques are being developed. When a standard formula for the best possible exposure has been finalized, this will become the standard for future work.

Consideration of sample size poses a difficult dilemma. In order to statistically detect a 10% difference in injury rate at levels in the 0-20% range we would require sample sizes of 100-300 fish. Detection of 5% difference in injury rate would require samples of 500 to 1,000 fish. Obviously, such large sample sizes are not practical. We will instead, utiilize samples of 50 fish whenever possible. This recognizes that data collected probably will not provide statistically valid comparisions, but should be sufficient to allow comparisons for management evaluation.

Appendix Table A1 (continued).

Electrofishing Injury Assessment
Field Survey Cover Sheet

Date:____________________ Observers:______________________________________

Stream:______________________ Reach:______________________________________

START	END
Time:____________________	Time:______________________________
H_2O Temp:__________________	H_2O Temp:___________________________
Turbidity:__________________	Turbidity:____________________________
Conductivity:________________	Conductivity:__________________________
Depth:____________________	Depth:______________________________

Equipment

Generator:____

Shocker Box:____

Anode:____

Cathode:____

Boat:____

Box Settings:____

Waveform:____

Power Gradient (V/CM):	1 inch __________	6 inch __________	12 inch ________
	2 feet __________	4 feet __________	8 feet ________
	12 feet__________	20 feet__________	20 feet ________
Peak Voltage:	1 inch __________	6 inch __________	12 inch ________
	2 feet __________	4 feet __________	8 feet ________
	12 feet __________	20 feet__________	

General Observations

(Include relative effectiveness, fish response, fish recovery time, etc.)

Appendix Table A2. Field survey cover sheet.

ELECTROFISHING INJURY ASSESSMENT
Field/Lab Sample Analysis

Collection Date: ______________ Autopsy Date: ______________ Stream: ______________________________ Reach: ______________________
Species: __________________ Autopsied By: __________________________ X-Ray Date: __________________ X-Rayed By: ___________________

Fish #	Length (In.)	Weight (lbs.)	Sex	Maturity	Hemorrhages			Spinal Damage			Rib Separation	Observations
					#	Severity	Position	#	Severity	Position		

Appendix Table A3. Field/lab sample analysis form.

Appendix Table B1. Physical parameters associated with electrofishing injury study samples collected during 1991.

Sample Code	Date	Stream	Species	Sample Size	Water Temp. (°F)	Conductivity (umhos/cm)	Boat	Generator	Anode Configuration	Cathode Configuration	Shocker Type	Shocker Settings	Waveform	Catch Rate
1A	4/3/91	Willow Cr.	Rainbow	50	----	----	----	----	----	----	Fish Trap Controls	----	----	----
1B	4/9/91	Willow Cr.	Rainbow	30	43	195	----	Honda 350W	12 In. Ring	6 Ft. Cable	Coffelt Mark 10 Backpack	350V Output	CPS	----
1C	4/9/91	Willow Cr.	Rainbow	30	43	195	----	Honda 350W	12 In. Ring	6 Ft. Cable	Coffelt Mark 10 Backpack	250V Output	Pulsed DC 60Hz Square	----
2A	5/16/91	Madison R.	Brown	50	43-54	300	15 Ft. Fiberglass Drift	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	1,000-1,500 Watt Output	Smooth DC	0.63 Fish/Min.
2B	5/16/91	Madison R.	Brown	50	43-54	300	15 Ft. Fiberglass Drift	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	600-1,000 Watt Output Half-Pulse	Rectified AC 60Hz Sine	0.66 Fish/Min.
2C	5/16/91	Madison R.	Brown	50	43-54	300	15 Ft. Fiberglass Drift	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	500-800 Watt Output Full-Pulse	Rectified AC 60Hz Sine	0.68 Fish/Min.
2D	5/16/91 & 5/20/91	Madison R.	Rainbow	56	43-54	300-320	15 Ft. Fiberglass Drift	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	1,000-1,500 Watt Output	Smooth DC	0.58 Fish/Min.
2E	5/16/91 & 5/20/91	Madison R.	Rainbow	47	43-54	300-320	15 Ft. Fiberglass Drift	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	600-1,000 Watt Half-Pulse	Rectified AC 60Hz Sine	0.53 Fish/Min.
2F	5/16/91 & 5/20/91	Madison R.	Rainbow	45	43-54	300-320	15 Ft. Fiberglass Drift	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	500-800 Watt Full-Pulse	Rectified AC 60Hz Sine	0.51 Fish/Min.
3A	5/9/91 & 5/10/91	West Fork & mainstem Bitterroot R.	31 Rainbow 8 Cutt.	39	39-42	33-55	15 Ft. Aluminum Drift w/sheathed bow	Honda 2,500 W & Gillette 4,500 W	Two 4-dropper arrays of 1/4" cable	Hull (Stern 1/3)	Coffelt VVP 2C	400V Output	Rectified AC 60Hz Sine	0.18 Fish/Min.

Appendix Table B1 (Continued)

Sample Code	Date	Stream	Species	Sample Size	Water Temp. (°F)	Conductivity (umhos/cm)	Boat	Generator	Anode Configuration	Cathode Configuration	Shocker Type	Shocker Settings	Waveform	Catch Rate
3B	5/10/91	West Fork & mainstem Bitterroot R.	9 Rainbow 3 Cutt.	12	39-42	35-55	15 Ft. Aluminum Drift w/sheathed bow	Honda 3,500 W	Two 4-dropper arrays of 1/4" cable	Hull (Stern 1/3)	Coffelt Mark 22	450-600V Output (5 Amps)	CPS	0.13 Fish/Min.
3C	5/9/91	West Fork Bitterroot R.	35 Rainbow 7 Cutt.	42	40-42	33-34	15 Ft. Aluminum Drift w/sheathed bow	Honda 3,500 W	Two 4-dropper arrays of 1/4" cable	Hull (Stern 1/3)	Coffelt Mark 22	---- (1 Amp)	Pulsed DC 60Hz Square	0.33 Fish/Min.
3D	5/22/91	Bighorn R.	Rainbow	46	45-52	880-900	18½ Ft. Aluminum Sled	Onan 6,500 W	Two 6-dropper arrays of 1/4" cable	Hull	Coffelt VVP 15	220 V Output (11 Amps) 20% Pulse Width	Pulsed DC 60Hz Square	0.46 Fish/Min.
3E	5/22/91	Bighorn R.	Rainbow	54	45-52	880-900	18½ Ft. Aluminum Sled	Onan 6,500 W	Two 6-dropper arrays of 1/4" cable	Hull	Coffelt VVP 15	300 V Output (16 Amps)	Smooth DC	0.57 Fish/Min.
3F	8/26/91 - 8/28/91	Swan R.	Rainbow	23	55-56	150-175	15 Ft. Aluminum Drift w/sheathed bow	Honda 2,500 W	Two 4-dropper arrays of 1/4" cable	Hull (Stern 1/3)	Coffelt VVP 2C	125 V Output	Rectified AC 60Hz Sine	----
3G	9/3/91	Swan R.	Rainbow	21	50-59	177	15 Ft. Fiberglass Drift	Gillette 4,500 W	10 In. Aluminum Triangle (1" wide)	11 Sq. Ft. Stainless Plate	Leach 220 Volt	1,000-1,500 Watt Output	Smooth DC	0.09 Fish/Min.
3H	9/4/91	Swan R.	Rainbow	26	50-54	158	15 Ft. Aluminum Drift w/sheathed bow	Gillette 4,500 W	One 4-dropper array of 1/4" cable w/screen trailers	Hull (Stern 1/3)	Coffelt Mark 22	425 V Output (11 Amps)	CPS	0.19 Fish/Min.
3I	9/16/91	Bighorn R.	Rainbow	44	64	540	18½ Ft. Aluminum Sled	Onan 6,500 W	One 6-dropper array of 3/8" cable w/screen trailers	Hull	Coffelt Mark 22	300 V Output (22 Amps)	CPS	0.41 Fish/Min.

Appendix Table B1 (Continued)

Sample Code	Date	Stream	Species	Sample Size	Water Temp. (°F)	Conduc-tivity (umhos/cm)	Boat	Generator	Anode Configur-ation	Cathode Configur-ation	Shocker Type	Shocker Settings	Waveform	Catch Rate
3J	9/16/91	Bighorn R.	Rainbow	28	64	540	18½ Ft. Aluminum Sled	Onan 6,500 W	One 6-dropper array of 3/8" cable w/screen trailers	Hull	Coffelt VVP 15	200 V Output (15 Amps)	Smooth DC	2.80 Fish/Min.
5A	9/17/91	Yellow-stone R.	5 Shovel-nose 1 Walleye	6	52	600	18 Ft. Aluminum Sled	Honda 5,000 W	Coffelt Electro-sphere	Hull	Coffelt VVP 15	200 V Output (12 amps)	Pulsed DC 60Hz Square	0.08 Fish/Min.
5B	9/17/91	Yellow-stone R.	6 Sauger 3 Shovel-nose	9	52	600	18 Ft. Aluminum Sled	Honda 5,000 W	Coffelt Electro-sphere	Hull	Coffelt Mark 22	300 V Output (12 Amps)	CPS	0.18 Fish/Min.
5C	10/91	Yellow-stone R.	Sauger	20	45	≈ 500	18 Ft. Aluminum Sled	Honda 5,000 W	Coffelt Electro-sphere	Hull	Coffelt VVP 15	600 V Output (20 Amps)	Pulsed DC 60Hz Square	----
6A	6/26/91	W. Fork Hyalite Cr.	Grayling	25	43	33	Plastic Sled (crawdad)	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	Wire screen inside perforated PVC cylinder	Leach 220 Volt	300-350 Watt Output	Smooth DC	----
6B	6/26/91	W. Fork Hyalite Cr.	Grayling	25	43	33	Plastic Sled (crawdad)	Gillette 3,500 W	10 In. Aluminum Triangle (1" wide)	Wire screen inside perforated PVC cylinder	Leach 220 Volt	200 Watt Output Half-Pulse	Rectified AC 60Hz Sine	----
7A	7/29/91	Ulerys Lake	Rainbow	19	----	----	----	----	----	----	Gill Net Controls	----	----	----
7B	6/12/91	Cliff Lake	Rainbow	16	----	----	----	----	----	----	Gill Net Controls	----	----	----
8A	8/91	Bozeman Fish Tech. Center	Rainbow	19	39	238	----	----	----	----	Hatchery Controls	----	----	----
8B	8/91	Bozeman Fish Tech. Center	Rainbow	20	39	238	----	Tanaka 300 W	10" wire Diamond	10" wire Diamond	Coffelt BP-6 Backpack	340 Volt Output	Pulsed DC 250 Hz Square	----
8C	8/91	Bozeman Fish Tech. Center	Rainbow	24	39	238	----	Tanaka 300 W	10" wire Diamond	10" wire Diamond	Coffelt BP-6 Backpack	340 Volt Output	Pulsed DC 250 Hz Square	----

Appendix Table B2. Injury rates by severity class for both autopsy and x-ray of samples collected for electrofishing injury study during 1991.

					INJURY (%)					
					HEMORRHAGE (AUTOPSY)			SPINAL DAMAGE (X-RAY)		
Sample Code	Sampler Type	Species	Sample Size	Length Range (Inches)	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
1A	Control	Rainbow	50	16.4-20.2	4.0	0	0	0	0	0
1B	Backpack CPS	Rainbow	30	15.7-19.7	23.3	46.7	6.7	6.7	0	3.3
1C	Backpack 60 Pulse	Rainbow	30	16.0-20.5	10.0	40.0	6.7	0	6.7	6.7
2A	Mobile Smooth DC	Brown	50	11.7-19.9	4.0	2.0	0	8.0	0	0
2B	Mobile Half-Pulse	Brown	50	12.3-17.8	18.0	10.0	0	20.0	4.0	8.0
2C	Mobile 60 Pulse	Brown	50	11.9-22.0	32.0	16.0	8.0	16.0	8.0	12.0
2D	Mobile Smooth DC	Rainbow	56	12.0-17.0	19.6	1.8	3.6	5.4	1.8	5.4
2E	Mobile Half-Pulse	Rainbow	47	12.9-17.2	36.2	29.8	6.4	17.0	6.4	6.4
2F	Mobile 60 Pulse	Rainbow	45	12.3-17.0	26.7	33.3	8.9	15.6	17.8	8.9
3A	Boom 60 Pulse	Rainbow/ Cutthroat	39	9.4-17.6	33.3	33.3	20.5	28.2	17.9	12.8
3B	Boom CPS	Rainbow/ Cutthroat	12	11.9-16.8	8.3	16.7	0	16.7	0	0

Appendix Table B2 (Continued)

					INJURY (%)					
					HEMORRHAGE (AUTOPSY)			SPINAL DAMAGE (X-RAY)		
Sample Code	Sampler Type	Species	Sample Size	Length Range (Inches)	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
3C	Boom 60 Pulse	Rainbow/ Cutthroat	42	12.0-16.9	33.3	40.5	16.7	35.7	11.9	19.0
3D	Boom 60 Pulse	Rainbow	46	10.4-21.0	17.4	21.7	19.6	37.0	19.6	10.9
3E	Boom Smooth DC	Rainbow	54	8.9-20.8	33.3	9.3	16.7	33.3	3.7	13.0
3F	Boom 60 Pulse	Rainbow	23	9.6-19.0	21.7	17.4	21.7	21.7	0	30.4
3G	Boom Smooth DC	Rainbow	21	9.7-18.6	0	0	0	4.8	0	0
3H	Boom CPS	Rainbow	26	9.2-16.9	11.5	15.4	0	3.8	0	0
3I	Boom CPS	Rainbow	44	7.9-21.8	15.9	15.9	2.3	27.3	11.4	4.5
3J	Boom Smooth DC	Rainbow	28	10.6-21.3	0	0	10.7	7.1	0	10.7
5A	Boom 60 Pulse	Shovel- nose/ Walleye	6	13.1-36.0	0	0	0	0	0	0
5B	Boom CPS	Sauger/ Shovel- nose	9	18.3-30.5	0	0	0	0	0	0
5C	Boom 60 Pulse	Sauger	20	12.7-20.7	0	0	0	0	0	0
6A	Mobile Smooth DC	Grayling	25	14.6-17.9	0	0	0	0	0	0

Appendix Table B2 (Continued)

					INJURY (%)					
					HEMORRHAGE (AUTOPSY)			SPINAL DAMAGE (X-RAY)		
Sample Code	Sampler Type	Species	Sample Size	Length Range (Inches)	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
6B	Mobile Half-Pulse	Grayling	25	15.2-16.9	4.0	0	0	0	0	0
7A	Control	Rainbow	19	8.5-11.5	---	---	---	0	0	0
7B	Control	Rainbow	16	14.2-18.3	12.5	0	0	0	0	0
8A	Control	Rainbow	19	11.0-14.5	---	---	---	0	0	0
8B	Backpack Pulse	Rainbow	20	11.0-14.5	---	---	---	0	5.0	0
8C	Backpack Pulse	Rainbow	24	11.0-14.5	---	---	---	16.7	8.3	4.2